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A METEOROLOGICAL MEASUREMENT SYSTEM  
FOR SUPPORT OF ATMOSPHERIC PROPAGATION STUDIES

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A METEOROLOGICAL MEASUREMENT SYSTEM FOR SUPPORT  
OF ATMOSPHERIC PROPAGATION STUDIES

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ABSTRACT

In support of laser system design and testing, the Atmospheric Sciences Laboratory (ASL) at White Sands Missile Range (WSMR), New Mexico, has designed, developed, and implemented a system for meteorological data acquisition, transmission, and processing. The system covers optical turbulence, wind, gases, and particulates. The system has been in operation for 2 years and is currently being used to characterize the atmosphere at a high energy laser facility at WSMR.

Optical turbulence instrumentation includes point measurements with a spatial temperature probe, integrated measurements over a 180-m horizontal path with an optical scintillometer, and vertical profiles up to 600 m with an acoustic sounder. Wind speed and direction are monitored with a UVW anemometer system.

Gases currently being monitored for concentration include water vapor, ozone, total hydrocarbons, methane, nitrous oxide, and carbon dioxide. Particulate measurements include those of size distribution, mass concentration, and scattering coefficient.

Stations at each data acquisition site acquire, preprocess, convert, transmit, and/or store data. The stations are linked to a central computer through bidirectional computer-controlled data links. The central computer handles the data collection, archiving, and formatting.

1. INTRODUCTION

The ASL at WSMR has been active in the study of atmospheric effects on electro-optical (EO) and laser systems for a number of years. Adequate characterization of the atmosphere for these systems required development of a specialized field research measurement system. Such a measurement system was initially developed in 1971 and first fielded in 1972.

In 1976 the ASL was requested to provide meteorological support at the High Energy Laser

System Test Facility (HELSTF) at WSMR. This support consisted of two phases: (1) development of a data base at the HELSTF and (2) direct operational support. The research system is currently providing the data base at the HELSTF. However, in deference to project requirements for atmospheric data during operational support and in realization of the maintenance-intensive nature of the research system, it was recognized that a somewhat less sophisticated, but at the same time more flexible, system would be required for direct operational support. The development of the support system would then free the research system for other field studies of laser propagation.

The primary purposes of this paper are: (1) to present a general description of the research field measurement system, (2) to describe the operational system for HEL support in detail, and (3) to comment on remote sensors currently under evaluation.

2. FIELD MEASUREMENT SYSTEM

2.1 Research

2.1.1 Design

Development of the field research system began in 1971 with the requirement to provide measurements of atmospheric conditions in support of field testing of EO and laser systems. The primary atmospheric effects requiring characterization were optical turbulence, crosswind, and extinction coefficient (due to both gases and particulates). The research system, designated the Meteorological Optical Measuring System (MOMS III), was designed initially as a mobile data collection system with limited on-board processing capability.

The MOMS III system contains three major subsystems: (1) sensors, (2) data acquisition and transmission, and (3) data processing. The primary interface between the sensors and the data processing is a data input/patch network where any individual channel or group of channels can be routed as necessary. Sensor/signal calibration-attenuation and analog monitoring are accomplished before digital conversion. Raw and/or averaged data are then

recorded on magnetic tape; semireal-time evaluation requires computer manipulation with results displayed either graphically or numerically. Since this system was designed to provide research grade measurements, it has been used extensively to assist in the evaluation of specialized crosswind and optical turbulence point and remote sensors.

### 2.1.2 Sensors

The MOMS III system is currently used to provide a detailed data base at the HELSTF at WSMR. The near-surface data base for the natural background at this facility encompasses optical turbulence, crosswind, gases, and particulates. The instrumentation (primarily point sensors) used to provide the measurements is summarized in table 1.

**2.1.2.1 Spatial Temperature Probe.** This device was developed in-house at the ASI and measures temperature difference between vertically separated (20 cm) probes. The amplitude difference is converted to an rms signal calibrated at 1.0 V DC = 1°C. Specific processing yields the optical turbulence ( $C_N^2$ ) value.

**2.1.2.2 Wind Speed and Direction.** The R. M. Young UVW orthogonal anemometer system measures winds between 0.2 and 23 m sec<sup>-1</sup> with standard

low-threshold propellers. The system is calibrated through spinning a component at 1800 rpm for a calibration value of 9.6 m sec<sup>-1</sup>.

### 2.1.2.3 Water Vapor (H<sub>2</sub>O). The General

Eastern 1200 AP Dew Point/Temperature System measures the dewpoint via the cooled mirror/platinum thermometer method. Internal system calibration is provided. One unit has been calibrated at the National Bureau of Standards (NBS) and all other units are checked and compared to the NBS calibrated units.

**2.1.2.4 Ozone (O<sub>3</sub>).** Ozone is monitored by a Dasibi ultraviolet (uv) absorption type analyzer. This analyzer ratios the signal from the source through the sample gas with ozone scrubbed (to set the 100 percent level) to the signal from the source through the sample gas with ozone. All sampling lines are teflon. Calibration is by generating ozone from a stable uv source.

### 2.1.2.5 Total Hydrocarbons/Methane (THC/CH<sub>4</sub>).

Total hydrocarbons and methane are measured with a Horiba Flame Ionization Detector (FID) type analyzer. This instrument ionizes any carbon atoms in the sample in a flame and measures the resulting current flow. The current flow is then converted to a display in ppm as carbon. To determine the methane content of the sample, the sample is first passed through

TABLE 1. ATMOSPHERIC POINT MEASUREMENTS

Element	Unit
Optical Turbulence	Spatial temperature probe (in-house)
Crosswind	R.M. Young UVW AN/GMQ-11 or WS-101
Gases (concentration)	
H <sub>2</sub> O	General Eastern Dewpoint 1200 AP
O <sub>3</sub>	Dasibi 1003 AH
THC/Methane	Horiba FIA-21
N <sub>2</sub> O	Miran II
CO <sub>2</sub>	Horiba AIA-23
Particulates	
Size distribution	Particle Measuring Systems DAS-64 w/CSASP-100 and ASASP-300 probes
Mass concentration	GCA Mass Monitor APM-1
Scattering coefficient	Meteorology Research Inc. Integrating Nephelometer 1550-B
Gases and/or Particulate	
Absorption coefficient	CO <sub>2</sub> and DF laser spectrophone (in-house)

a heated catalyst which oxidizes the higher hydrocarbons. This unit is calibrated through use of sample gases in known concentrations.

**2.1.2.6 Nitrous Oxide ( $N_2O$ ).** Nitrous oxide is monitored by a Wilks Miran II analyzer, a straight infrared absorption photometer which has a spike filter in the absorption path to isolate the  $N_2O$  band. This instrument utilizes a white cell to obtain the necessary absorption path length. The instrument is not, however, completely species specific and appears to suffer from some, as yet indeterminate, interferences. The unit is calibrated through use of specific gas concentrations.

**2.1.2.7 Carbon Dioxide ( $CO_2$ ).** Carbon dioxide is measured with a Horiba nondispersive infrared analyzer; but this analyzer, unlike the simple absorption cell type like the MIRAN, utilizes a compensating or correlation cell and an acoustic detector to greatly increase species specificity. In addition, a spike filter is also used to isolate a particular absorption band. The unit is calibrated through use of specific gas concentrations.

**2.1.2.8 Particulates.** Measurements of the size distribution of atmospheric particulates are made with a Particle Measuring Systems light-scattering aerosol counter (see table 1). By coupling these measurements with realistic assumptions about the complex refractive index and the shape of the particulates, Mie theory computations may be used to estimate the particulate extinction coefficient. The instruments to measure mass concentration and scattering coefficient have not been field tested.

**2.1.2.9 Spectrophone.** The laser spectrophone system was developed in-house at the ASL and provides relatively direct in situ field measurements of both the gas and particulate absorption coefficients. The basic approach was to measure the gaseous absorption with one spectrophone and the gaseous plus particulate contribution with another. The electrical difference between signals is the particulate contribution.

### 2.1.3 Data Acquisition

The system utilizes high maintenance, medium-life sensors requiring a large resource investment of time and manpower to set up, calibrate, and operate even over relatively short test periods, i.e., 24 to 72 hours. The system must be manned continuously to provide for quick response and minimum data loss during sensor/system failure.

Optical turbulence and crosswind are measured at selected tower levels. Gases and particulates are usually measured within a few meters of the ground.

### 2.1.4 Data Processing

The heart of the MOM III system is a Hewlett Packard 2100S minicomputer and associated peripherals. This system processes the data from the sensors.

The turbulence, wind, and gas data are sampled at a frequency of 1 Hz. These values are arithmetically averaged over 10 sec and the 10-sec averages are recorded on magnetic tape. Subsequently, the 10-sec samples are arithmetically averaged over 15 min. Measurements of particulate size distribution are cumulative over periods of 10 to 15 min. The processed data may be graphically displayed (CRT and/or hard copy) and tabulated.

## 2.2 Operational

### 2.2.1 Design

For direct operational support, the meteorological support system depicted in figure 1 was conceived. The system, designated the High Energy Laser - Meteorological Data Analysis System (HEL-MDAS), is to be fabricated, tested, and installed at the HELSTF by the summer of 1982. Measurements are made at fixed sites (firm power) along the centerline of the HEL firing corridor and from a network of mobile sites (battery/solar power). The former measurements are made at four locations: (1) 0-m test cell complex, (2) 500-m receiver/target site, (3) 1-km site, and (4) 2-km site. A 16-m bulwark sensor platform and a 32-m tower are located at the 0-m test cell complex. A gas/aerosol van and a 32-m tower are located at the 500-m receiver/target site. A single

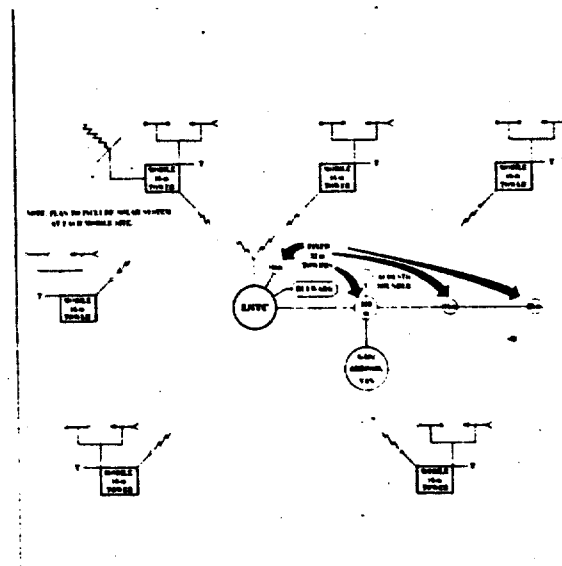


Figure 1. Conceptual HELMET support system for the HELSTF at White Sands Missile Range, New Mexico

32-m tower is located at each of the 1-km and 2-km sites. Measurements from the surrounding area are made from six portable 16-m towers. Data stations at each of the 12 sites electronically transfer information to the HEL-MDAS in the Laser Systems Test Center (LSTC). The HEL-MDAS handles the final data managing, archiving, and modeling.

## **2.2.2 Sensors**

The overall sensor configuration is illustrated in figure 2.

### **2.2.2.1 Fixed 32-m Towers**

a. Point Measurements. Standard sensor packages are located at the 8-, 16- and 32-m levels. The standard sensor package consists of wind speed and direction (WDS), temperature (T), barometric pressure (P) and, optimally, water vapor. Wind is measured by a cup and vane system, temperature by a shielded platinum sensor, pressure by a pressure transducer, and water vapor by an aspirated mirror-dewpoint/temperature system. Specialized sensors for gases and aerosols similar to those utilized in the research system are located at the 500-m site.

b. Path Measurements. Remote sensors for optical turbulence and crosswind are also located at certain levels.

2.2.2.2 Bulwark Sensor Platform. This site consists of a 16-m (approximately) meteorological tower rigidly affixed to the northeast face of the protective bulwark for test cell 1 at the 0-m test cell complex. Fixed point sensors located at the 16-m level provide near field effect measurements of wind speed and direction, optical turbulence, air temperature, and pressure. Additional point, integrated path, and/or path profile sensors may be incorporated in the future.

2.2.2.3 Mobile 16-m Towers. A 16-m crank-up tower with a sensor package of wind speed, wind direction, and temperature at the 8- and 16-m levels is located at each of six remote sites which are located at distances up to 8 km from the LSTC. The data are used as a basis for a 15- to 30-min predictive capability. Sensors, data acquisition, and relay link are battery/solar powered.

## **2.2.3 Data Acquisition, Preprocessing, and Transmission**

2.2.3.1 General. Data stations are located at each data acquisition site to acquire, preprocess, convert, transmit, and/or store data. Multiple 8-channel data stations are installed at the bulwark sensor platform, at each of the four fixed 32-m towers, and at the gas/aerosol van. Single 8-channel data stations are located at each of the six mobile 16-m towers. All data stations slave to the HEL-MDAS via an appropriate bidirectional computer-controlled data link and

transmit data to the HEL-MDAS on command. The fixed tower and gas/aerosol van stations communicate with the HEL-MDAS via a flexible RS-232-C compatible hardware/fiber optic link; the link between the mobile tower stations and the HEL-MDAS is via an RS-232-C compatible radio link.

2.2.3.2 Equipment. In general, standard commercial or in-house modified standard commercial equipment is used. In either case, documentation is available. Hardware has been made as universal as possible by using the full power of the microprocessor to adapt with sensors and to allow maximum flexibility in data gathering and processing. Scaled versions of the same hardware and operation program instructions are employed for all towers and the van.

The initial controlling software has been developed to provide for flexibility in check-out and system testing. More advanced programs are developed as operational usage dictates. The remote stations are battery operated and use CMOS circuitry and power reduction techniques wherever possible. Data stations for the towers and van use identical cards with the multiplex board of the remote stations being only partially loaded, i.e., 8 channels. Figure 3 is a block diagram of the basic data station. Neither unit contains the EPROM data-storage system, but provision is made for future addition. The stations operate without the need for air conditioning, but will not have to operate in the direct sun. Each station is enclosed in a weatherproof container with some degree of air circulation.

a. Modems. The system is modem limited; i.e., it transmits data as accurately and rapidly as the link allows. Commercial modems are used for phone (hardware) and/or fiber optic link. The radio modem was developed internally. Each remote station answers to its own Identification Address with query and reporting occurring on different frequencies.

b. Recording. The individual data collection/processor units do not currently provide any nonvolatile data storage capability. The processor systems are capable of expansion to include EPROM storage capability. In addition, an RS-232 compatible read/write cassette deck is available commercially and could be purchased for use with the system when a stand-alone mode is required.

2.2.3.3 Programming. The data collection systems are programmable at two levels.

a. Operational PROM Resident Program. The basic operational program with default values controlling channels to be scanned, gain setting, and integration time are stored in PROM and are automatically executed unless different values are set from keyboard or data link. The basic PROM resident executive program can be changed to allow the hardware to

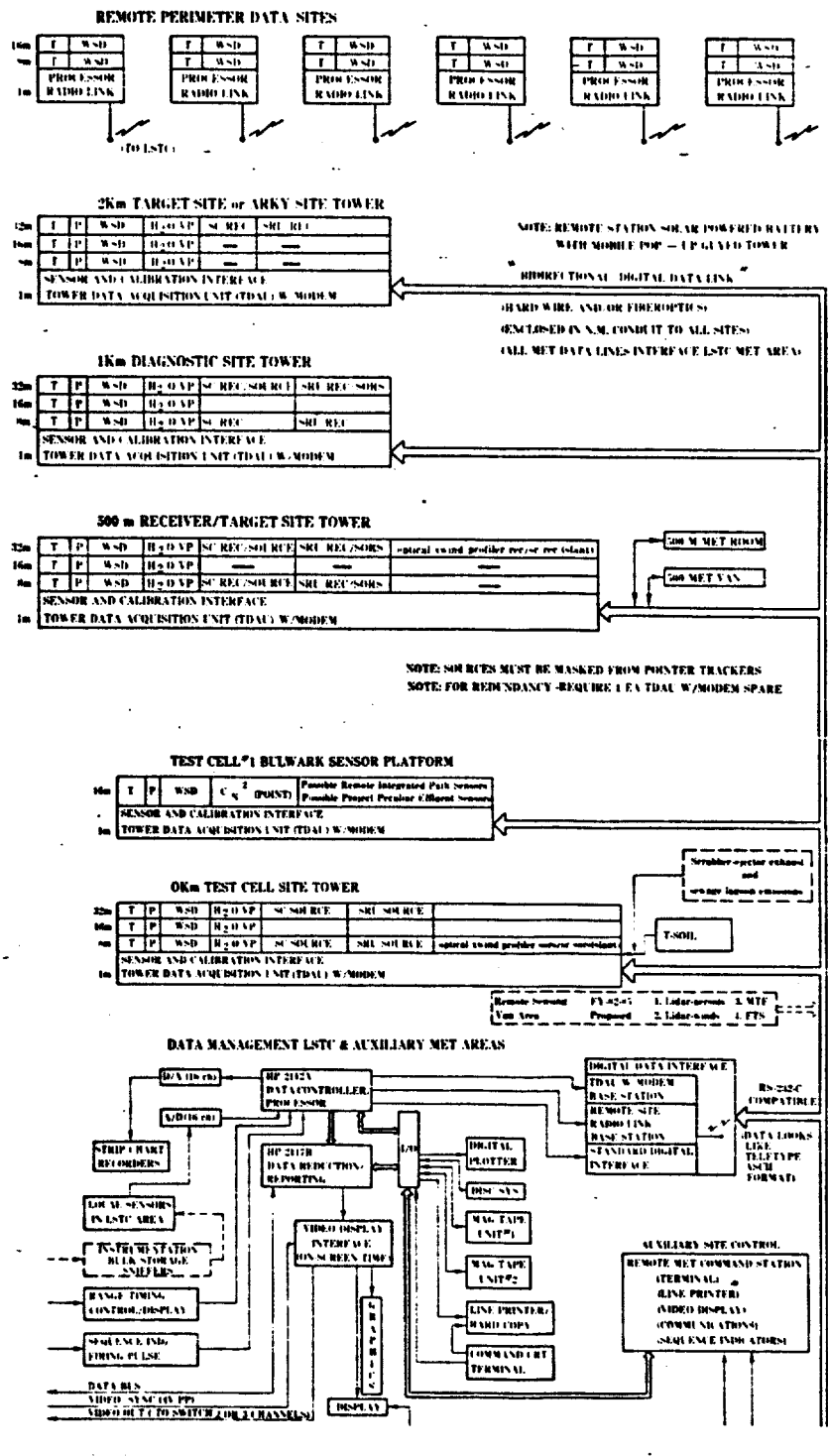


Figure 2. Block diagram of the HELNET Support System for the HELSTF at White Sands Missile Range, New Mexico.

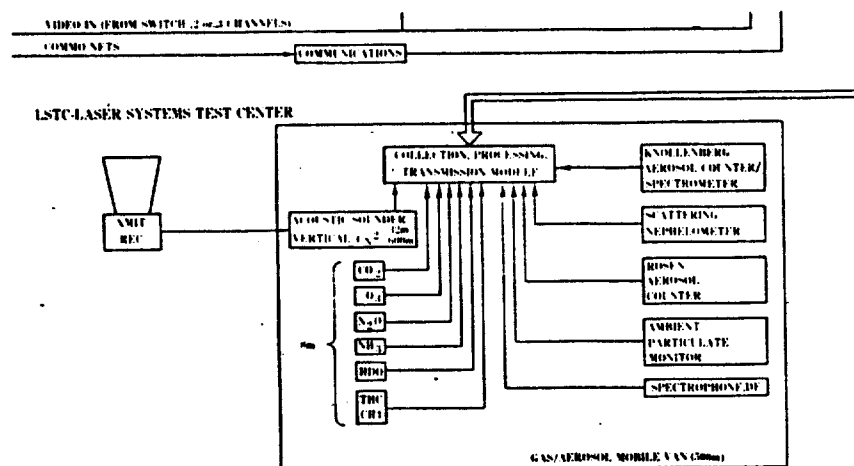
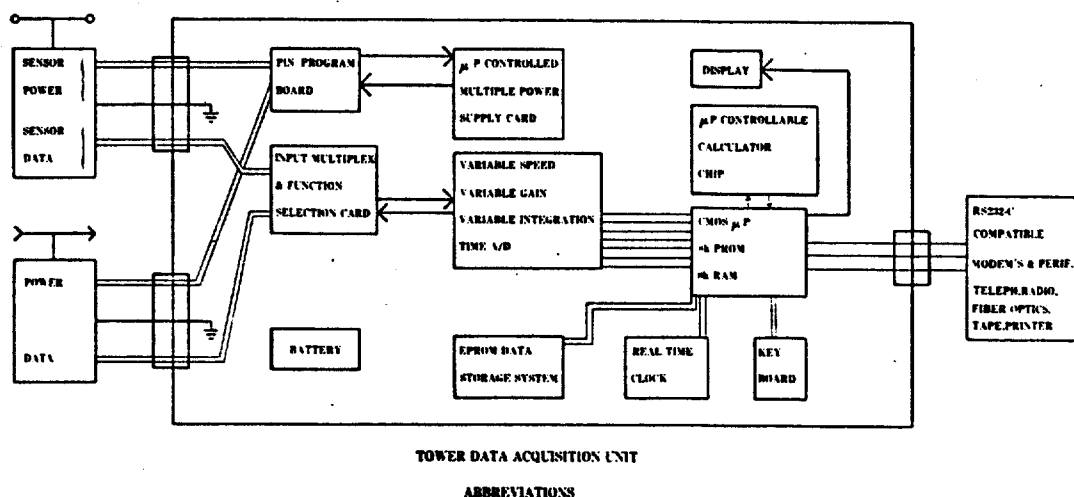


Figure 2 (cont)



#### ABBREVIATIONS

CH <sub>4</sub>	- METHANE	REC	- RECEIVER
C <sub>N</sub>	- OPTICAL TURBULENCE	SC	- SCATTERING NEPHELOMETER, MOBILE IP
H <sub>2</sub> O VP	- WATER VAPOR PRESSURE	SOURCE	- SOURCE
IP	- INTEGRATED PATH	SRC	- RADIATION RESISTANT XWIND SENSOR, MOBILE XWIND IP
LSTC	- LASER SYSTEMS TEST CENTER	SYNC	- SYNCHRONIZATION SIGNAL
MAG	- MAGNETIC	TELEPH	- TELEPHONE
μP	- MICROPROCESSOR	T	- TEMPERATURE
NM	- NON METALLIC	TBC	- TOTAL HYDROCARBON
P	- PRESSURE	WSD	- WIND SPEED/DIRECTION
		XMIT	- TRANSMITTER
		XWIND	- CROSSWIND

Figure 3. Block diagram of the remote station data acquisition units.

operate in any other desirable mode. Programming at this level, however, requires considerable knowledge of the system and the microprocessor language.

b. RAM Programming. Changes entered via keyboard or data link change operational program default values that control channels scanned, gain setting, integration time, average time, output processing subroutine used, clockset, and conversion factors. When the power to the unit is removed and then restored, these factors are lost and the PROM resident default values are executed.

### 2.2.3 Final Data Processing

The HEL-MDAS handles the long-term meteorological data storage and final data processing for HELSTF. The final data processing system is block diagrammed in figure 2. There are two Central Processing Units (CPU): The Data Controller/Processor (DCP) and the Data Reduction/Reporting (DRR). The DCP handles data collection, archiving, and formatting for efficient transfer to the information processing CPU. Model calculations and information display occupy the full capability of the DRR. The dual CPU concept also allows for backup operation (albeit at a reduced level) if one CPU should fail before or during a test.

The most accurate information is of no value if not available to the test director when needed. For long-range predictions, test personnel come to the LSTC Meteorological Center; but during the test, information is displayed in the HELSTF control rooms via video switch link. Graphical summary information is available real time on a CRT, and detailed information is available in hard copy from the line printer following a test. The CRT is divided into four graphical sections and a fifth section for flashing reverse format messages. The four graphical sections of the CRT contain:

Current meteorological conditions along anticipated beam path.

Short-term prediction of meteorological conditions along anticipated beam path.

Current trajectory and density of laser plume.

Predicted contour intensity plots of on-target irradiation calculated by using current meteorological conditions in a simple propagation code.

The fifth section is used to flag important meteorologically related events such as an approaching air mass discontinuity, plume drift into the beam path, or sensor failure.

### 3. REMOTE SENSORS

The basic instrumentation currently used either in the research or the operational support system is primarily point type, i.e., capable of sensing data at a single point or small volume. However, whereas point measurements may be adequate for characterizing the conditions along a fixed horizontal path near the ground, their utility for moving path scenarios (horizontal and slant) is certainly questionable. This led to the consideration, development (as required), and utilization of advanced or remote sensors. Table 2 summarizes the candidate sensors/systems. These sensors would provide either integrated path\* or path profile† measurements. To date, two remote sensors, both developed by National Oceanic and Atmospheric Administration, have been evaluated and incorporated in the HEL-MDAS system: (1) optical turbulence scintillometer and (2) acoustic sounder.

The horizontal integrated path sensor for optical turbulence is an optical scintillometer. The scintillometer device uses a new optical technique to measure the refractive index structure parameter,  $C_N^2$ , over an integrated path through the use of large receiving optics and an extended incoherent transmitter. This technique avoids problems arising from the saturation of scintillation, thus allowing a  $C_N^2$  measurement range from  $10^{-16}$  to  $10^{-12-2/3}$  over a usable path length of 150 to 500 m. The scintillometer has been validated for ranges of 3- to 32-m above ground at WSMR.

The vertical path profile sensor for optical turbulence is an acoustic sounder. The sounder utilizes an acoustic echo return technique to determine inversion levels and associated optical turbulence values derived from these inversion/temperature gradients. The sounder provides usable data to a height of 150 to 300 m with severe noise limitations at greater altitudes. The sounder has been validated for these ranges at WSMR.

The other remote sensors/systems listed in table 2 capable of providing wind and extinction coefficients due to gases and particulates are being evaluated.

\*Integrated path - an averaged, but usually weighted, value measured between two points.

†Path profile - average values for each of several segments between two points.

#### 4. SUMMARY

The ASL has developed two systems, one designed for research applications and the other for specific operational support, to study atmospheric effects on laser propagation. The research system utilizes maintenance-intensive, medium-life sensors with a large resource investment in time and manpower for development, test preparation, and real-time data quality checks. The operational system is designed to utilize low maintenance, long-life sensors with a large initial resource investment but lower operational costs.

An operational measurement system with one fixed tower site, one mobile site and a gas/aerosol van would cost \$440K to duplicate at the present time:

Mobile site	\$ 20K
Fixed tower site	30K
Gas/aerosol van	190K
Data transmission and processing	200K

The optical scintillometer and the acoustic sounder remote sensors are currently being used in data base evaluation. Other candidate remote sensors are being evaluated.

TABLE 2. ADVANCED SENSORS/SYSTEMS

Element	Sensor	Point (P) Integrated Path (IP) Path Profile (PP)	Horizontal (H) Vertical (V) Slant (S)
Optical Turbulence	Scintillometer	IP (H)	
	Acoustic Sounder	PP (V)	
Wind	FM-CW Radar	PP (S)	
	Pulsed Doppler Radar	PP (V)	
	Saturation Resistant Anemometer	IP (H)	
	Optical Crosswind Profiler	PP (H)	
	High Resolution Scanning Lidar	PP (S)	
	Laser Doppler Velocimeter	PP (S)	
	Tethered Aerodynamically Lifting Anemometer	P (V)	
	Fourier Transform Spectrometer	IP (H)	
Gas (concentration)	Differential Absorption Lidar	PP (S)	
Particulates	High Resolution Scanning Lidar	PP (S)	
Optical Turbulence, Crosswind, Gases, Particulates	Remotely Piloted Vehicle	PP (S)	

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